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Summary

The Federal Aviation Administration is trying to make its air traffic management system more responsive to the needs of the aviation community by exploring the concept of "free flight" for aircraft flying under instrument flight rules. In free flight, en route aircraft fly user (i.e., pilot or airline)-defined trajectories with only minimal air traffic control (ATC) adjustments to avoid restricted airspace and separation loss with other aircraft. Free flight is expected to allow airspace users more flexibility in determining optimal aircraft routing. In all current free-flight concepts, the efficient handling of aircraft in transition from en route to terminal airspace requires ground-based planning and control. When aircraft transition from en route to terminal airspace, their trajectories often must merge subject to in-trail separation or time-based flow constraints necessary for meeting airport capacity limitations. The unconstrained nature of free flight complicates these ground-based tasks even more. Hence, providing controllers with effective decision support tools that not only support free flight, but also support the transition of free-flight aircraft into the terminal airspace, is essential.

A logical first step toward free flight could be made without significantly altering current ATC procedures or requiring new airborne equipment by designing a ground-based system to be highly responsive to user preference in en route airspace while providing for an orderly transition to terminal areas. To facilitate user preference in all en route environments, a system based on an extension of the Center/TRACON Automation System (CTAS) is proposed in this report. The new system consists of two integrated components. An airspace tool (AT) focuses on unconstrained en route aircraft (e.g., not transitioning to the terminal airspace), taking advantage of the relatively unconstrained nature of their flights and using long-range trajectory prediction to provide cost-effective conflict resolution advisories to sector controllers. A sector tool (ST) generates efficient advisories for all aircraft, with a focus on supporting controllers in analyzing and resolving complex, highly constrained traffic situations. When combined, the integrated AT/ST system supports user preference in any air route traffic control center (ARTCC) sector. The system should also be useful in evaluating advanced free-flight concepts by serving as a test bed for future research. This document provides an overview of the design concept, explains its anticipated benefits, and recommends a development strategy that leads to a deployable system.

Introduction

The Federal Aviation Administration (FAA) is trying to make its air traffic management system more responsive to the needs of the aviation community by exploring the concept of "free flight" for aircraft flying under instrument flight rules. (See refs. 1 and 2.) In free flight, en route aircraft fly user (i.e., pilot or airline)-defined trajectories with only minimal air traffic control (ATC) adjustments to avoid restricted airspace and separation loss with other aircraft. Free-flight rules begin after the initial departure restrictions and end at the initiation of arrival sequencing to the destination airport's terminal airspace. Because en route aircraft in free flight are not required to follow ATC-preferred jet routes, free flight is expected to allow airspace users more flexibility in determining optimal aircraft routing. Although significant economic benefits are anticipated, very little is known about the effects of free flight across the national airspace.

Through the FAA's National Route Program (NRP), airlines currently can file requests to fly non-ATC-preferred routes (with some limitations). However, the complex interaction of user-preferred routing and dynamic changes in traffic density across the national airspace have limited the benefits of the program. (See ref. 3.) The problems experienced with NRP show that, if free-flight benefits are ever to be realized, the air traffic management (ATM) system will have to evolve through an FAA strategy of increasing decision support tools available to controllers, airlines, and pilots while gradually decreasing route constraints. In addition, this evolution must be accomplished safely and with no disruption in operations.

In current free-flight concepts, the efficient handling of aircraft in transition from en route to terminal airspace

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will continue to require ground-based planning and control. When aircraft transition from en route to terminal airspace, their trajectories often must merge subject to in-trail separation or time-based flow constraints necessary for meeting airport capacity limitations. The unconstrained nature of free flight complicates these ground-based tasks even more. Hence, providing controllers with effective decision support tools that not only support free flight, but also support the transition of free-flight aircraft into the terminal airspace, is essential.

A logical first step would be to achieve as many free-flight benefits as possible without significantly altering current ATC procedures or requiring expensive airborne equipment modifications. These benefits could be achieved by a ground-based system that is highly responsive to user preference in en route airspace while also providing for an orderly transition to terminal areas. User preference is the general term for any aircraft operation that is explicitly requested or assumed to be desired by the airline or pilot. Preferred aircraft operations can vary from non-ATC-preferred routings to the use of airborne vertical navigation (VNAV) automation during descents into terminal airspace. In a system that requires positive ATC control, user preferences are facilitated (or enabled) through verbal or procedural ATC clearances. Developing decision support tools for controllers that identify user preferences and their effects on the current traffic situation would enable controllers to quickly assess the effort of incorporating user preferences into the current traffic plan. Furthermore, by designing automation to determine the minimum change to the user preference required for incorporation into the traffic plan, a large step toward free-flight benefits would be achieved.

To facilitate user preference in all en route environments, a system concept based on an extension of the Center/TRACON Automation System (CTAS) has been developed. (See ref. 4.) It consists of two integrated components. An airspace tool (AT) focuses on unconstrained en route aircraft (e.g., not transitioning to the terminal airspace), taking advantage of the unconstrained nature of their trajectories and using long-range trajectory prediction to maximize user efficiency by providing cost-effective conflict resolution advisories to sector controllers. A sector tool (ST) generates efficient advisories for all aircraft, with a focus on supporting controllers in analyzing and resolving complex, highly constrained traffic situations. When combined, the integrated AT/ST system supports user preference in any air route traffic control center (ARTCC or Center) sector. This system should also be useful in evaluating more advanced free-flight concepts by providing a test bed for future research.

This document presents an overview of the design concept, explains its anticipated benefits, and recommends a development strategy that leads to a deployable system. The AT and ST are described in detail, and a new ATM position, the "airspace coordinator," is defined. Examples of conflict resolution for typical conflict scenarios are also given.

Functional Design

The integrated tools concept must accommodate the wide range of traffic environments found in the national airspace. At one extreme, generally associated with free flight, is an airspace consisting only of aircraft not constrained by traffic management or other localized, highly dynamic constraints. This environment, usually found in en route sectors well away from terminal airspace, is referred to in the following discussion as an "unconstrained" environment. If traffic density is low, very little ground-based ATC coordination or intervention is required. At the other extreme, in the en route area approaching an airport's terminal airspace, heavy traffic management is often required. Arriving aircraft must merge for sequencing while simultaneously adhering to crossing restrictions and avoiding conflicts with other aircraft. Referred to herein as "transitional," this traffic environment is characterized by a mix of unconstrained aircraft with many highly constrained aircraft transitioning to terminal airspace. Any traffic situation between these two extremes is possible in a single sector. The environment in a sector also changes, depending on the time of day. Adjacent sectors in a Center can have the same environment, or several sectors may represent a transition from one extreme to the other. Furthermore, a normally unconstrained en route sector can actually behave more like a transitional sector if an adjoining Center places traffic management (e.g., miles in trail or metering) restrictions on entering aircraft. The integrated concept facilitates the inclusion of user preferences in all these environments.

An overview of the integrated concept is shown in figure 1. The system is supplied with real-time radar track and flight-plan information from the Center Host computer or an advanced aircraft tracking system. The AT is independent of airspace sectorization, supporting a new "airspace coordinator" position whose objectives are maximizing user efficiency while reducing sector controller workload. The ST is sector controller centered, and facilitates traffic planning and intersector coordination within and between Centers. To minimize changes to current ATC procedures, all clearances issued to aircraft

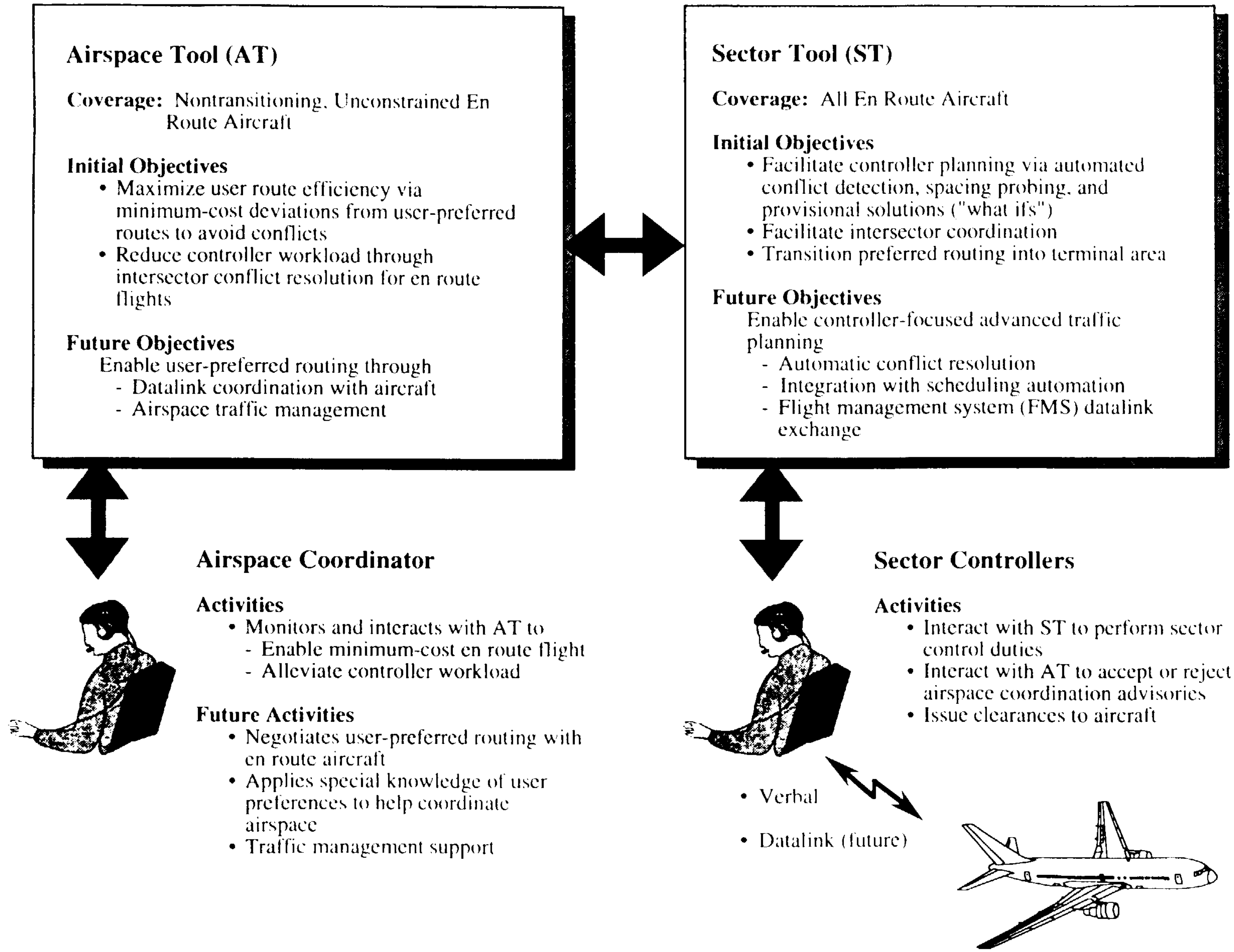


Figure 1. Airspace tool/sector tool functional concept.

are still issued by the sector controllers. Clearances based on advisories from the two tools or the airspace coordinator, however, reflect a much higher degree of user preferences integrated into current sector traffic planning.

Airspace Tool

The AT is designed to facilitate user preferences for en route flights that are not inhibited by localized, highly dynamic traffic constraints, generally for aircraft found outside high-density traffic areas and/or not transitioning to terminal airspace. The goal of the AT is to detect and resolve conflicts with a time horizon (approximately 20 to 25 minutes) that is longer than the "decision-making time horizon" used by sector controllers, defined as the time normally required to realize a desired traffic plan by issuing clearances to resolve conflicts and achieve traffic management constraints (if any). Since the AT looks beyond the controller's time horizon, the potential exists to resolve predicted conflicts more efficiently than waiting until the controller would normally detect them. AT resolutions are initially restricted to aircraft that are not affected by traffic management constraints since accurately predicting trajectories without detailed knowledge of the sector controller's traffic plan is difficult. The addition of these constrained aircraft to the AT would require that the increased benefits outweigh the negative impact of incorrectly predicting the traffic plan. Constrained aircraft are handled by the ST as discussed in the next section.

Cost-effective conflict resolution advisories reflecting minimum deviations from user-preferred routes are provided by the AT in the form of horizontal path, altitude, and/or speed changes. A packet consisting of the advisory and information from which the modified resolution trajectory can be reconstructed are sent to the ST for display and acceptance or rejection by the sector controller. If accepted, the advisory clearance is added to the known trajectory constraints for the affected aircraft (available to both the AT and ST for future trajectory predictions). If the advisory is rejected, the AT is notified so an alternative cost-effective resolution can be attempted.

The AT cost-effective resolutions are based on the concept that there is both an optimal clearance to resolve a predicted future conflict and an optimum time to issue that clearance (ref. 5). A resolution advisory is made up of a suggested clearance and a time for its initiation; for a cost-effective resolution, the time is chosen to achieve a trade-off between maneuver efficiency and conflict certainty. The earlier a maneuver is initiated, the more efficient and easily executed it will be. For example, a small speed change well in advance of a conflict is more efficient than an altitude change close to the point of conflict. However, resolution maneuvers made too far in advance may often be unnecessary if conflict probabilities are low. The later a maneuver is initiated, the less efficient it will be, but the more certain it is that the conflict would have occurred. The optimal time to initiate a maneuver is determined by minimizing the cost of maneuvering as a function of time. That function depends on the conflict probability (based on the trajectory prediction accuracy of both aircraft) and other parameters, such as the cost of a less-efficient flightpath and the level of controller workload required to resolve the conflict.

The AT supports a new controller position, called the "airspace coordinator" (AC), located in the ARTCC. This person monitors an area of airspace larger than a single sector, interacting with the AT to enhance its functionality. In an initial implementation of the concept, the AT will display a conflict to the AC, who may resolve the conflict either manually or in conjunction with AT automatic resolution support. The AC will then communicate the advisory directly to the appropriate sector controller for issuance or rejection. If several AC positions are desired within a Center, coordination among these positions will be necessary; this scenario will be included in a future implementation. By supporting a controller dedicated to identifying and resolving predicted conflicts beyond the decision-making time horizon of sector controllers, deviations from user-desired trajectories are expected to be minimized without greatly increasing the workload of sector controllers. Also, because the AC analyzes and resolves multisector conflicts while observing traffic in all affected sectors, efficient resolutions can be obtained while reducing the required coordination between sector controllers. The AC should be able to direct AT resolutions to controllers with less workload without disturbing controllers in high-workload situations. It is anticipated that many of the initial manual AC functions will be automated as understanding of desired solutions to typical problems increases.

Since the AT is designed to support the evolution of advanced concepts toward free flight, the AC position is expected to play an increasingly important role in future implementations of the concept. For example, the AC may eventually apply special real-time knowledge of user preferences (possibly after negotiation with the aircraft) to coordinate en route flights within Center airspace. This real-time knowledge will most likely be supplied by datalink or some alternative form of communication with the user (e.g., communication with the Airline Operations Center) that does not involve the sector controller. Because of the AC's "big picture" perspective of airspace operations, the AC's responsibilities will eventually include more of a traffic management role. Specifically, in future enhancements the AT may measure and predict en route complexity (within a sector and overall) to ensure that sector controller workload is maintained within acceptable bounds and if not, develop and implement plans to constrain aircraft routing so that traffic complexity is reduced. The AT, with the AC, represents an extension of current ATC procedures and, when implemented, will serve as a platform for evaluation of advanced free-flight concepts.

Figure 2 illustrates a possible AT interface to display all en route aircraft within a desired airspace region (e.g., greater than a single sector, possibly an entire area or Center) to the airspace coordinator, who has keyboard and trackball input devices for interacting with the tool. The interface, referred to as a dynamic conflict display, shows predicted conflicts and situational awareness information as well as pending AT resolution advisories. The display consists of a plan view representation of the airspace, showing the position of each aircraft, including requested data blocks. It is updated in real time (at intervals of 12 seconds or less) as new information, such as track updates, becomes available. Each aircraft with a predicted conflict is tagged; further information about the conflict (e.g., projected time to the conflict and resolution advisory) can be requested. In addition, the display provides the AC with a prediction of regions that will have high conflict density, which may impose a difficult traffic management workload on the sector controller. Conflict density may be represented as the sum of probabilities for conflicts predicted to occur in any sector. Three schemes for display of sector conflict densities are presented in the figure: the lower right panel shows ranges of times to conflict for each sector, along with the worst case; the upper right and left panels show the degree of sector conflict loading (possibly color-coded) with time in two different formats. The AC is expected to use the density information to prioritize the conflicts. The figure should not be considered a final display interface; significant effort must be devoted to make the interface as effective and easy to use as possible.

Sector Tool

While the AT is oriented predominantly toward accommodating the user, the ST must accommodate the user while also assisting the controllers. Its primary goal is to support sector controllers in safely and effectively managing complex traffic situations, such as those that occur in the transitional environment to terminal airspace, while facilitating as many user preferences as possible. Its design is based on the research performed for the descent advisor (DA) tool of CTAS (refs. 6 and 7). The ST serves as a situational display and intelligent-advisory aid, supporting the controller in devising and executing a plan for managing traffic in all environments, even those that are highly constrained by traffic management constraints (e.g., metering or miles in trail). As future traffic density increases and user preferences become more prevalent, the ST will be needed to handle higher traffic loads while enabling user-preferred trajectories to be extended further into the extended terminal area.

The ST assists controllers by generating accurate, fuel-efficient clearance advisories for the merging, sequencing, and separation of high-density traffic while providing automation assistance for the prediction and resolution of conflicts between aircraft in all phases of flight. It assists sector controllers by:

- determining efficient descent trajectories for each aircraft, from cruise altitudes to the boundary of the terminal airspace;
- detecting potential conflicts and providing interactive aids for planning resolutions; and
- providing real-time information to aid controllers in their overall traffic planning.

One of the major ST functions is to provide descent clearance advisories, which are based on four-dimensional fuel-efficient trajectory predictions for descents from cruise altitudes to terminal area feeder fixes. Traffic management constraints are met while deviations from user-preferred descent profiles are minimized. Through the use of rapid update cycle weather information (ref. 8) and aircraft models, the ST predicts trajectories that are of the same order of magnitude in accuracy as current airborne systems. The trajectory solutions are translated into ATC clearance advisories that include vector headings, cruise speed, aircraft top-of-descent (TOD) point, and descent speed profile (composed of a descent Mach number and/or an indicated airspeed). All ST advisories are continually updated to reflect changes in aircraft states and atmospheric predictions.

The ST uses automatic conflict detection to alert the controller to potential separation conflicts over the controller's entire decision-making time horizon. By using accurate aircraft trajectory predictions that reflect controller intent, the ST is expected to extend the current controller's decision-making time horizon, thereby enabling more efficient planning. The display of potential conflicts is timed to help the controller manage the airspace. The time of display may also be based on a conflict probability threshold (which may be set by the

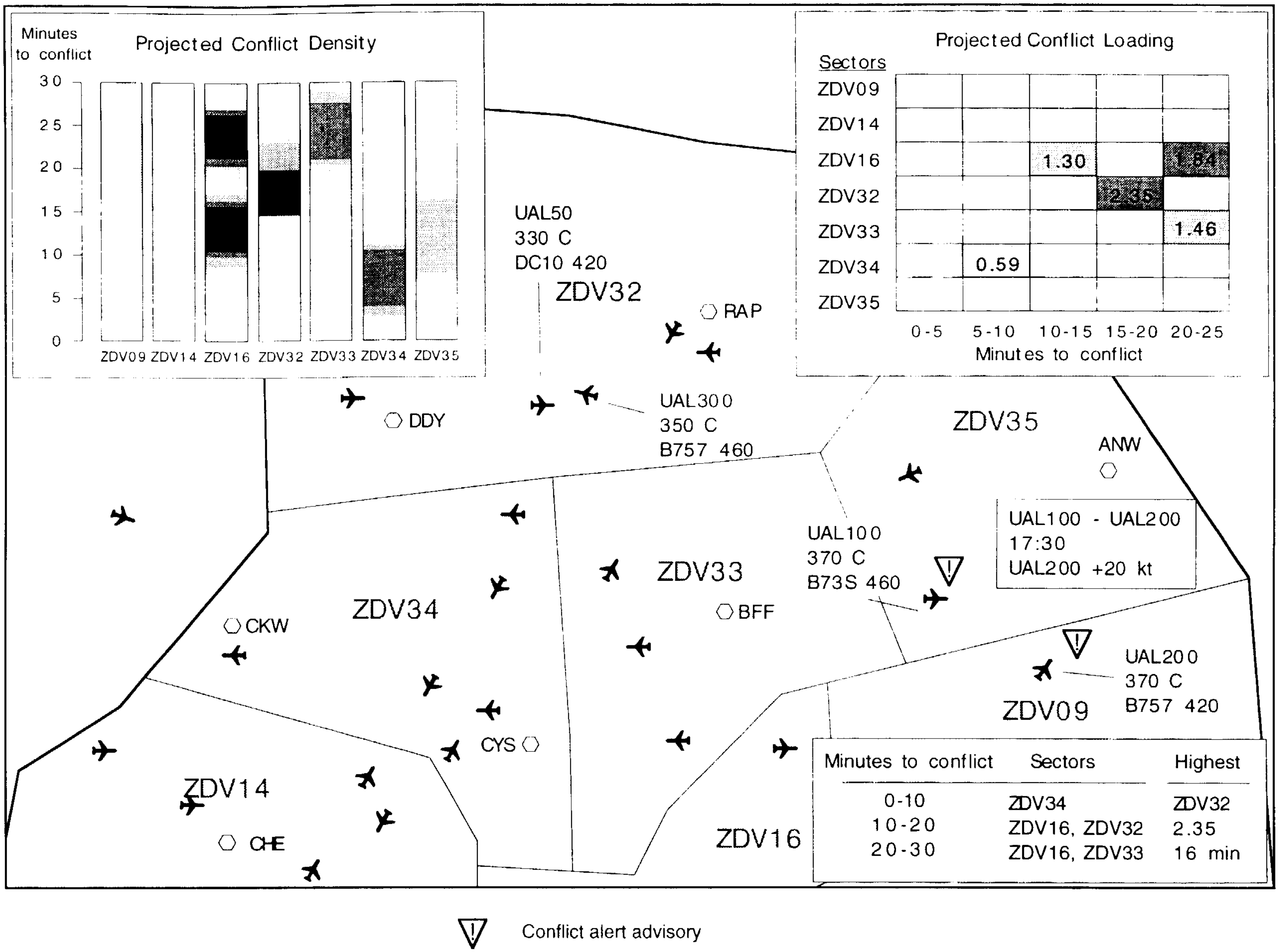


Figure 2. Dynamic conflict display (initial representation).

controller). In addition to providing more advance time for traffic planning, automatic detection should enable the controller to resolve conflicts more efficiently. The increased confidence provided by automatic conflict detection may also be useful in reducing the number of conservative clearances that controllers currently issue to ensure separation when they are unsure of whether a conflict will occur.

Automatic conflict detection at the ST level will initially be implemented to display only conflicts between:

- any pair of aircraft "owned" by that sector controller (independent of whether the conflict resides within the controller's sector);
- any "unowned" aircraft within a controller-defined distance (or time) from the sector boundary and any other such unowned aircraft or any owned aircraft; or
- any owned aircraft within a controller-defined distance (or time) from its next sector and any aircraft within that next sector or any aircraft within a specified distance (or time) from and due to arrive in that next sector.

To include probing the effects of other aircraft, the controller can manually identify the desired aircraft to be probed. Once an unowned aircraft has been identified, it is probed until the ST determines that it can no longer impact aircraft owned by the controller. Display of potential conflicts beyond sector boundaries to all sector controllers involved will facilitate the solution of multisector conflicts.

The ST can aid a sector controller to quickly create and evaluate a provisional ("what-if") plan through the use of provisional clearance feedback, which allows the controller to determine the effect of issuing a clearance without affecting other controllers or other parts of the automation system. In addition to provisional clearance feedback, controllers are expected to use the ST to provide information for maneuver feedback. For example, a controller may absorb required delay by turning an aircraft away from its intended metering fix, while observing a countdown in remaining delay to be absorbed. After the required amount of delay has been absorbed, the controller would turn the aircraft back on a path to the metering fix.

The ST also helps the controller to monitor aircraft spacing by displaying separation information at points along predicted trajectories. In-trail spacing can be shown at a defined location (e.g., at a Center or terminal airspace boundary) for selected streams of aircraft (e.g., aircraft exiting into a specified, adjacent Center or assigned to a defined meter fix). Alternatively, minimum separation locations can be shown for two or more aircraft to identify dynamic "choke points" for aircraft not on standard routes. The display includes options for showing all minimum separations, or just separations that are less than a specified value. The spacing function is expected to support the merging of traffic without requiring the traffic to conform to specific routes, altitudes, or speeds, a procedure often done to simplify predicting aircraft interactions. Spacing, provisional clearance feedback, and conflict detection are expected to greatly enhance the provisional planning capability of the sector controller.

To a sector controller, AT resolutions represent either solutions to problems beyond their normal planning horizon or very efficient solutions for conflicts between nontransitioning, unconstrained aircraft. When AT resolution advisories are received, the ST automatically checks the affected sector controllers to see if they are configured to accept AT resolutions. Sector controllers can configure the ST to automatically reject AT resolutions to their sector if they deem their traffic load too heavy to analyze resolutions beyond their current decision-making time horizons. If any controller is not accepting AT resolutions, a rejection is automatically sent to the AT without any notification to the sector controllers. If all affected sector controllers are accepting AT resolutions, then the ST checks the advisories for possible conflicts with all en route aircraft, using its controller-intent (i.e., provisional planning) information. It should be recalled that the AT is primarily concerned with unconstrained aircraft and that it has a limited knowledge of the often rapidly changing sector controller environment, so AT resolutions are not guaranteed, at this stage, to be conflict free. If a conflict is detected, the ST checks to see if the affected sector controllers are configured to accept AT resolutions that have potential conflicts. Again, sector controllers can configure the ST to automatically reject AT resolutions that are not conflict free if they deem their traffic load to be too heavy to analyze this information. If all affected controllers are configured to accept the AT resolution, the ST displays the AT conflict information, any conflict information generated at the ST level, and the suggested resolution to the appropriate sector controller(s). If the resolution can be worked into the sector controller's plan, the controller accepts the AT advisory and issues the clearance(s) to the aircraft; otherwise, the AT is notified of the resolution being rejected.

Future objectives for the ST will continue to focus on sector controller traffic planning. The addition of automatic or semi-automatic conflict resolutions will further reduce controller workload and facilitate inter-sector coordination. Automatic resolution techniques designed for the CTAS DA (ref. 9) are directly applicable to ST traffic problems. Integration with improved scheduling automation will allow the ST to automatically take time-based traffic management constraints into account. Finally, exchange of information between the ST and airborne flight management systems (FMSs) has the potential to greatly reduce frequency traffic and clearance adherence errors (ref. 7).

As in the current plan-view display (PVD), the ST displays to each sector controller all the aircraft tracks visible within a selected area. Superimposed on this display is any appropriate ST and/or AT advisory information being considered by that controller. The controller always has the option of removing all AT and/or ST advisories from the display. The ST display interface is based on the interface used in the DA; it provides keyboard-trackball input, and is updated in real time (typically every 12 seconds or less) as new information (e.g., track updates and controller inputs) becomes available.

All display features will ultimately be integrated into an advanced display (such as the display system replacement, or DSR), but some features may appear in early development phases on an auxiliary display interface, as shown in figure 3, where an example of controller interaction with the ST is shown. In the figure, flight UAL001 must be delayed to meet a desired crossing time (13:01) at the TOMSN metering fix while avoiding a conflict with overflight UAL002. Through interacting with the ST's provisional planning tools, the controller has determined that a horizontal path stretch with turnback directly to TOMSN is a workable solution. In this case, the controller issues the path stretch clearances to UAL001 at the turnout and turnback points, followed by a descent clearance approximately 30 n. mi. prior to the TOD point. The AT-detected conflict between UAL100 and UAL200 is also shown with supporting information. The AT resolution advisory of a 20-knot indicated air speed (KIAS) reduction is shown on the fourth line of the data tag for UAL200. (Note that the fourth line is used for illustrative purposes only.) The AT and ST advisories will be designed so the controller can easily distinguish between them, possibly through color-coding or blinking. The figure should not be considered a final display interface; significant effort will be devoted to make the interface as effective and easy to use as possible.

Integrated AT/ST Tools

The needs of any en route traffic environment can be met through integration of the AT and ST. In a completely unconstrained en route environment, a high percentage of AT resolution advisories are expected to be accepted by the sector controllers and issued as clearances to the aircraft, thereby facilitating user preferences. Traffic management planning in this environment is generally low, so the controller is able to treat the AT resolutions like current user requests. In a transitional environment with numerous aircraft arriving to the terminal airspace, the sector controller is concerned primarily with devising and executing a plan for managing traffic flow. Therefore, the cost-effective resolutions provided by the AT will likely conflict with the controller's traffic plan and will often be replaced by the provisional planning solutions of the ST. For a highly congested, unconstrained, en route environment with many randomly scattered conflicts, the AT and ST each contributes to the traffic management solution: the AT provides a dynamic display of high-conflict areas to aid in airspace coordination, and the ST aids the controller in executing a traffic management plan. Since most traffic environments are a mixture of constrained and unconstrained aircraft, it is expected that, in general, both the AT and the ST will contribute to facilitating user preferences in all en route sectors.

Table 1 summarizes the conflict detection and resolution capability differences between the two tools for an initial implementation. The AT considers unconstrained, nontransitioning, en route aircraft only since it is not integrated with the traffic planning provisional solutions necessary to handle flights transitioning to the terminal area. For transitioning aircraft, required traffic management constraints are achieved while facilitating as many user preferences as possible; the ST handles this environment. The AT resolutions are designed to handle conflicts beyond the controller decision-making time horizon, assuming no changes in either the aircraft's current path or its altitude. By definition, aircraft transitioning to/from the terminal area require large speed and altitude changes within the controller's decision-making time horizon. Departing aircraft can be handled by the AT outside of terminal airspace if the climb segment is not constrained by traffic management restrictions. (Note: Satellite departures are considered transitioning aircraft if they are transitioning to a nearby airport.) Because the AT is intended to provide coordination over all en route airspace, its conflict detection responsibilities include the entire Center. For each sector, the ST is responsible for conflict detection over each sector controller's planning horizon, which typically includes the controller's sector and neighboring sectors.

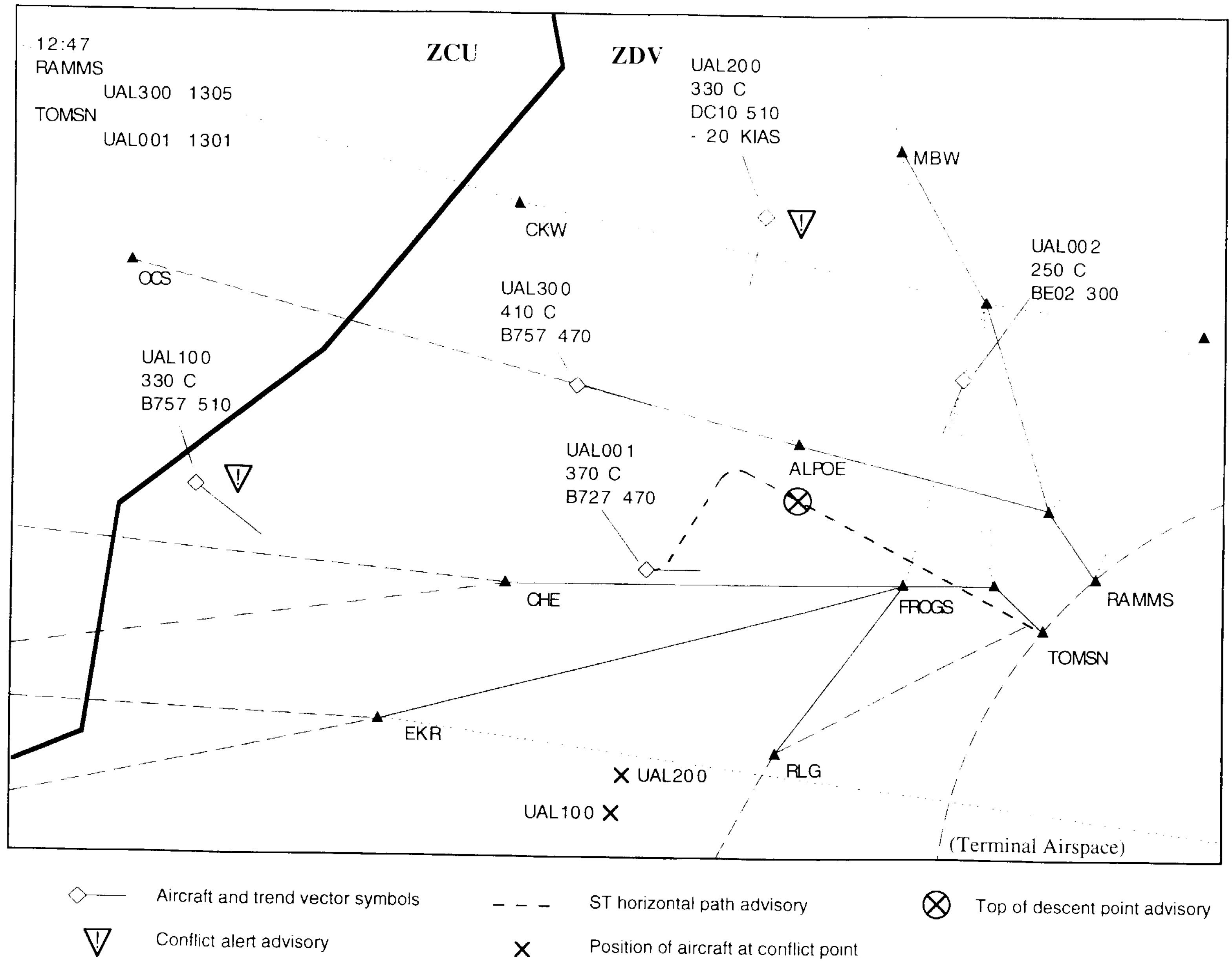


Figure 3. Sector controller prototype display (initial representation).

Table 1. Initial AT/ST conflict probing characteristics

	Airspace tool	Sector tool
Aircraft probed	Unconstrained en route traffic only	All en route traffic
Trajectory constraints	None	Traffic management
Detection responsibility	Entire Center airspace	For each sector, all aircraft within sector and individual aircraft in neighboring sectors
Conflict displayed to	AC[a] for resolution	SC(s)[b]
Conflict resolution	AC resolves conflicts with AT and sends to ST (AC can negotiate resolutions with sector controllers) SC issues clearances	SC manual resolution (aided by ST through provisional planning aids)
Resolution type	Cost-effective trajectory with provisional planning aids	ST provisional planning aids

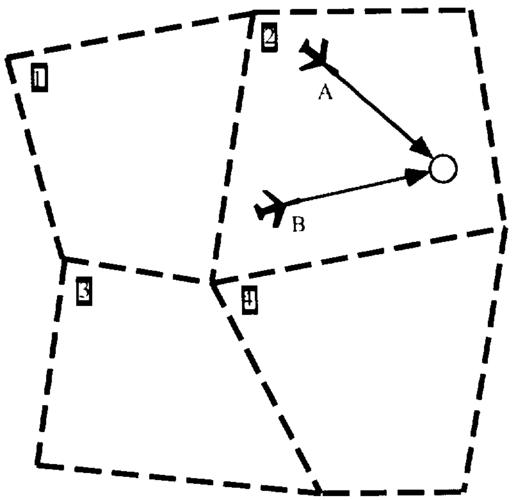
[a]AC = Airspace Coordinator
[b]SC = Sector Controller

In order for the cost-effective AT resolutions to have an impact in an environment in which the AT and ST are working together to facilitate user preferences for a mixture of both unconstrained and constrained aircraft, the resolutions must be available to the sector controller before the conflict is within the controller's decision-making time horizon. Work based on current prediction accuracy suggests that these cost-effective resolutions would generate advisories approximately 10 to 14 minutes in advance of the conflict (ref. 5), a time that is expected to be within the prediction horizon needed for the ST. However, reference 5 indicates that increasing trajectory prediction accuracy increases the advance time of the minimum-cost point. One prediction error source is the existing FAA radar tracking algorithm of the Center Host computer. Using an advanced radar tracking system (ref. 10) is expected to improve prediction accuracy, thereby enabling minimum-cost resolutions 20 or more minutes in advance. The system is now in place for testing at the Denver ARTCC, and its accuracy is being verified through analysis of flight-test data.

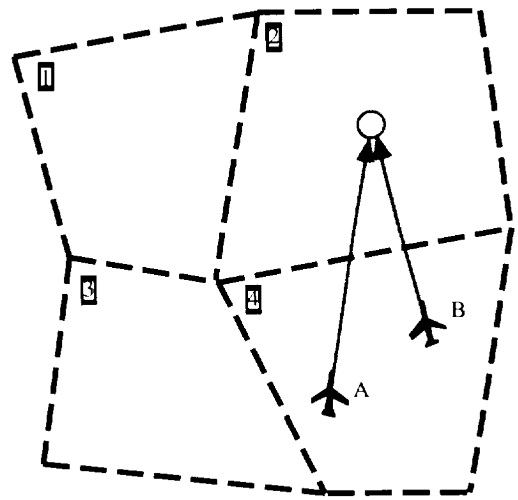
Conflict Resolution Scenarios

Since much of the concept relies on providing increased flexibility (e.g., routing) for users, considerable attention has been given to determining how the integrated tools will help resolve conflicts. In this section, the anticipated operation of the tools is described in some detail for several conflict scenarios. The expected benefits of the integrated tools in each traffic environment are also discussed. Four typical separation conflict scenarios are identified in figure 4. Consider the numbered areas to be sectors within a Center. In the figure, the sectors are shown to be horizontally adjacent, but the scenarios also hold for vertically adjacent sectors. They even hold for adjacent sectors in different Centers, although the coordination between facilities will be more complicated. For convenience in the discussions that follow, all the conflicts are shown to occur in sector 2.

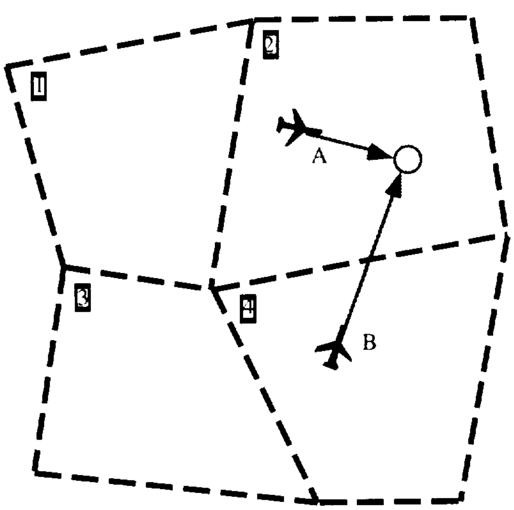
Figure 4(a) shows an example of an "intrasector" conflict, the situation where both aircraft and the predicted point of conflict (i.e., initial loss of minimum separation requirements) are within a single sector. This scenario should yield the most straightforward resolution since only one controller is involved. A somewhat more complicated scenario, an "external" conflict, is shown in figure 4(b): both aircraft are in one sector, and the point of conflict is in another. Figure 4(c) shows an "external intruder" scenario: one aircraft and the predicted conflict point are in one sector, and the other aircraft is in another sector. Figure 4(d) shows an "intersector" conflict, where the two aircraft are in different sectors and the predicted conflict point is in a third sector. The latter two scenarios generally require the greatest amount of coordination between controllers.



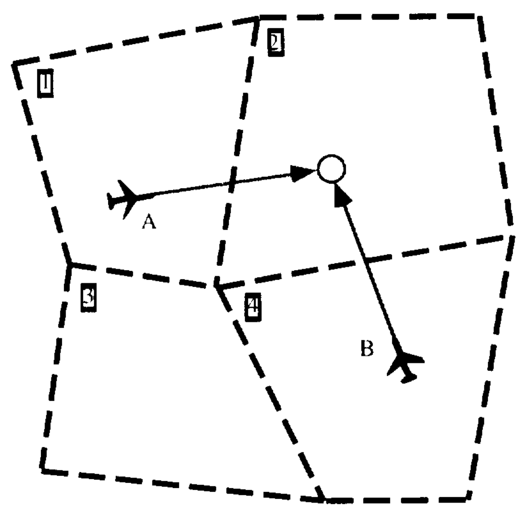
(a) "Intrasector" conflict.



(b) "External" conflict.



(c) "External Intruder" conflict.



(d) "Intersector" conflict.

Figure 4. Typical conflict scenarios in a multisector environment.

Three of these scenarios (b, c, d) may involve the coordination of two or more sector controllers. The ST facilitates efficient intersector coordination by identifying which controllers need to be made aware of conflicts and then displaying conflict information accordingly. In some cases where aircraft owned by different controllers are involved, the ST may notify both affected controllers or only the controller that would be expected to resolve the conflict. By displaying the conflict to the controller who can most efficiently resolve a conflict before displaying to other affected controllers, efficient resolutions can be facilitated. In other cases, the ST may notify a controller to contact another sector to negotiate a solution. It may also be possible to use the ST automation and display aids to facilitate efficient negotiation between sectors. In this case, controllers will have the capability to share their provisional planning information during negotiation, greatly simplifying the coordination process currently done by phone.

The ST uses "controller awareness" boundaries to define the horizon for displaying conflict detection results within adjacent sectors. Each adjacent sector pair (e.g. sectors 1 and 2) is represented by four awareness boundaries, two for traffic flowing in each direction. Figure 5 illustrates the two boundaries for traffic flowing from sector 1 (upstream sector) to sector 2 (downstream sector):

- *Upstream controller's awareness boundary:* a specified distance or time from the downstream sector within which the upstream controller becomes aware of conflicts between upstream aircraft within the horizon and aircraft in the downstream sector
- *Downstream controller's awareness boundary:* a specified distance or time from the downstream sector within which the downstream controller becomes aware of conflicts between upstream aircraft within the horizon and other upstream aircraft within the horizon or aircraft in the downstream sector

The distance or time that defines a boundary may be defined as a function of aircraft type (e.g., jet versus turboprop or unconstrained versus transitioning). Recall that ST-detected conflicts between aircraft in the same sector are displayed to the controller who owns the aircraft as long as the conflict is within the controller's decision-making time horizon, independent of the sector in which the conflict resides, so no awareness boundary is required for this case. Downstream controller awareness boundaries are used for display of both ST and AT conflict information. The downstream controller may configure display criteria for AT information separately from ST information. The upstream controller boundary is necessary only for ST conflict information since AT resolutions are assumed to be for conflicts beyond the upstream controller's decision-making time horizon.

When an aircraft crosses a controller's awareness boundary, the ST displays information to that controller about conflicts between the aircraft and any other aircraft in the downstream sector or any aircraft that has also crossed that awareness boundary. In figure 5, aircraft A is predicted to have a conflict in the downstream sector. When aircraft A crosses the awareness boundary for the upstream controller (SC1), the ST displays the conflict information to SC1; when the aircraft crosses the awareness boundary for the downstream controller (SC2), the conflict information is displayed to SC2. The positions of the boundaries are configurable (and interchangeable); they are expected to be set by mutual agreement between coordinating controllers. By interchanging the order that an aircraft crosses the boundaries, the adjacent sector controllers can define, on a sector-by-sector basis, which controller (upstream or downstream) will be aware of the conflict first (i.e., who will have the first attempt at resolving the conflict). It is unclear at this time whether two or just one combined boundary will be necessary in all or some environments. During development, human factors research will be performed to determine the number and best sequence of awareness boundaries to most effectively resolve multiple controller resolutions. The use of awareness boundaries is more fully described in the scenarios that follow; one combined awareness boundary is assumed in all references to intersector coordination unless otherwise noted.

In the following analysis, operation of the integrated tools is described for each conflict scenario in two traffic environments: a completely unconstrained en route environment and a transitional environment with many aircraft transitioning to a terminal airspace. An overview of the expected integrated system behavior is presented in table 2. As previously discussed, in a completely unconstrained en route environment, the AT is expected to detect most conflicts and provide cost-effective resolutions. In a transition to terminal airspace environment, the ST is expected to be the primary tool, and AT resolutions will be used only if they do not adversely impact the controller's traffic plan. Although these factors might affect the display options a controller would select or how a controller might respond to an AT advisory, the logic for each scenario presented in figures 6(a) through 6(d) and discussed in the following sections should be considered independent of the traffic environment.

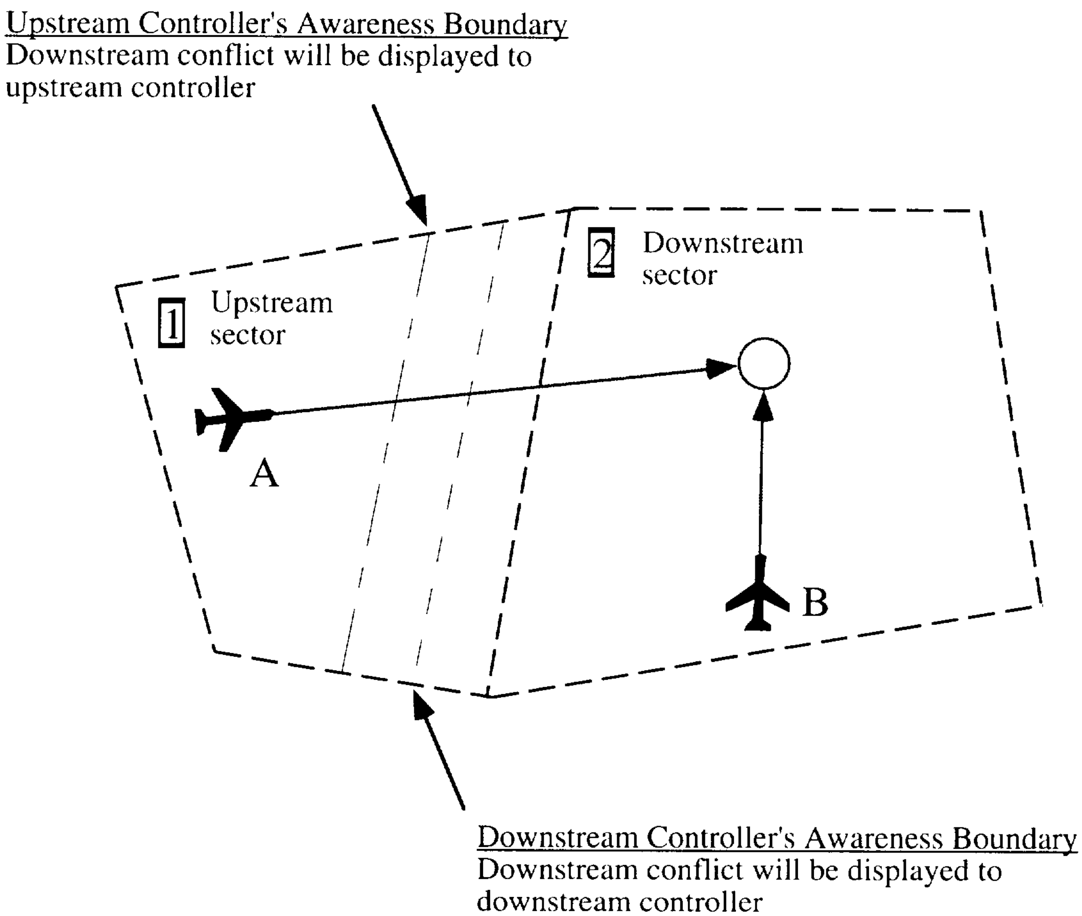
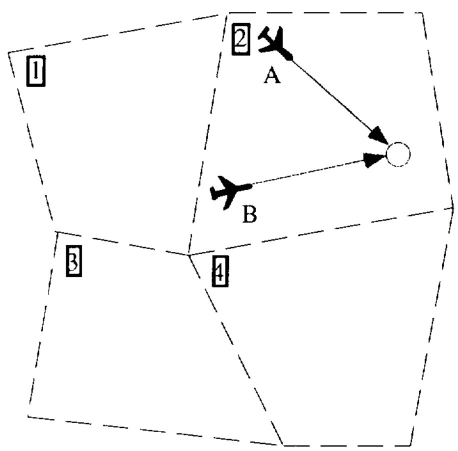


Figure 5. Intersector coordination boundaries.

Table 2. Expected conflict resolution behavior of the AT/ST system

Conflict type	**Unconstrained environment**	**Transitional environment**
	AT resolutions predominant; ideally AT resolves before SC "sees" conflict	ST resolutions predominant since many aircraft are transitioning (AT resolutions are likely to conflict with traffic plan)
Intrasector	SC accepts AT resolution when conflict identified earlier by AC; cost-effective solution desirable	AT resolutions used only if they do not interfere or conflict with arrival plan
External	Aircraft owner resolves conflict Option: alert conflict owner to negotiate resolution Display of conflict to conflict owner facilitates early handoffs	Aircraft owner "sees" conflict and resolves it, even if not probing other aircraft within conflict sector Display of conflict to conflict owner facilitates early handoffs
External intruder	Either SC (or both) resolves conflict, selected by AC/AT based on situation If one SC rejects AT resolution, AC/AT can try other SC	Conflict detected by ST when intruder is within probing range of conflict sector Either SC (or both) resolves conflict
Intersector	Either SC (or both) resolves conflict, selected by AC/AT based on situation If one SC rejects AT resolution, AC/AT can try other SC Option: alert conflict owner to negotiate resolution Display of conflict to conflict owner facilitates early handoffs	Conflict displayed by ST when both aircraft are within awareness boundaries of conflict sector Either SC (or both) resolves conflict Display of conflict to conflict owner facilitates early handoffs



Intrasector Conflict:

Aircraft A owned by SC2
Aircraft B owned by SC2
Conflict in sector 2

SC Sector Controller
ST Sector Tool
AC Airspace Coordinator
AT Airspace Tool

When AT detects a conflict:

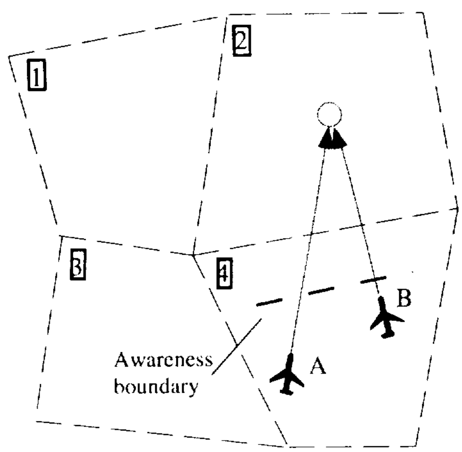
AT displays conflict to AC;
AC/AT resolves one/both trajectories;
AT sends conflict/resolution to ST.
If SC2 has configured ST to accept:
  ST probes resolution for conflicts, displays probe results and the resolution to SC2.
  If SC2 accepts resolution:
    SC2 issues clearance(s)
  or:
    Persistent conflict will be handled by ST.
SC2/ST notifies AT/AC of decision.

When ST detects a conflict:

ST displays conflict to SC2;
SC2/ST resolves one/both trajectories;
SC2 issues clearance(s).

(a) "Intrasector" scenario.

Figure 6. Conflict resolution.



External Conflict:

Aircraft A owned by SC4
Aircraft B owned by SC4
Conflict in sector 2

SC	Sector Controller
ST	Sector Tool
AC	Airspace Coordinator
AT	Airspace Tool

When AT detects a conflict:

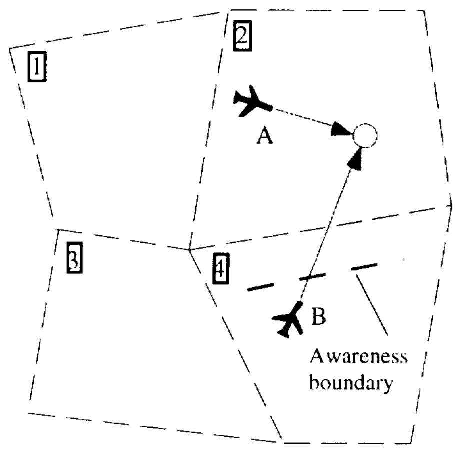
AT displays conflict to AC;
AC/AT resolves one/both trajectories;
AT sends conflict/resolution to ST.
If SC4 has configured ST to accept:
  ST probes resolution for conflicts, displays probe results and the resolution to SC4;
  ST may display conflict and message to SC2.
  If SC4 accepts resolution:
    SC4 issues clearance(s)
  or:
    Persistent conflict will be handled by ST.
SC4/ST notifies AT/AC of decision.

When ST detects a conflict:

ST displays conflict to SC4;
ST may display conflict and message to SC2.
If SC2 obtains handoffs of both aircraft:
  SC2/ST resolves one/both trajectories;
  SC2 issues clearance(s)
or:
  SC4/ST resolves one/both trajectories;
  SC4 issues clearance(s).

(b) "External" scenario.

Figure 6. Continued.



External Intruder Conflict:

Aircraft A owned by SC2
Aircraft B owned by SC4
Conflict in sector 2

SC Sector Controller
ST Sector Tool
AC Airspace Coordinator
AT Airspace Tool

When AT detects a conflict:

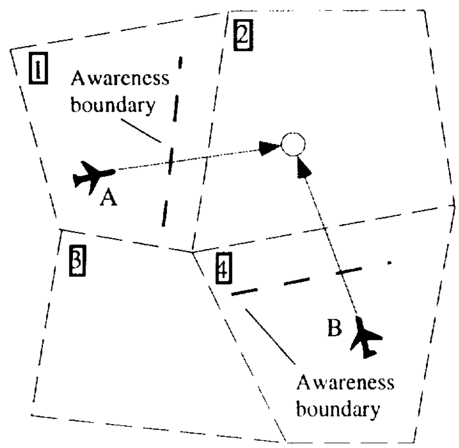
AT displays conflict to AC;
AC/AT resolves one trajectory (aircraft A);
AT sends conflict/resolution to ST.
If SC2 has configured ST to accept:
  ST probes resolution for conflicts, displays probe results and the resolution to SC2;
  If SC4 has configured ST to accept:
    ST displays conflict and message to SC4.
  If SC2 accepts resolution:
    SC2 issues clearance to aircraft A.
SC2/ST notifies AT/AC of decision.
If resolution for aircraft A is rejected:
  AC/AT resolves trajectory for aircraft B or persistent conflict is handled by ST.

When ST detects a conflict:

ST displays conflict to both SC2 and SC4 when within awareness boundary;
SC2/ST resolves trajectory for A, and/or negotiates with SC4 to resolve B
(SC2 may request early handoff from SC4);
SC2 and/or SC4 issue clearance(s).

(c) "External Intruder" scenario.

Figure 6. Continued.



Intersector Conflict:

Aircraft A owned by SC1
Aircraft B owned by SC4
Conflict in sector 2

SC	Sector Controller
ST	Sector Tool
AC	Airspace Coordinator
AT	Airspace Tool

When AT detects a conflict:

AT displays conflict to AC;
AC/AT resolves one trajectory (aircraft A);
AT sends conflict/resolution to ST;
If SC1 has configured ST to accept:
  ST probes resolution for conflicts, displays probe results and the resolution to SC1;
  If SC4 has configured ST to accept:
    ST displays conflict and message to SC4;
  If SC2 has configured ST to see conflicts:
    ST displays conflict and message to SC2.
  If SC1 accepts resolution:
    SC1 issues clearance to aircraft A.
SC1/ST notifies AT/AC of decision.
If resolution for aircraft A is rejected:
  AC/AT resolves trajectory for aircraft B or persistent conflict is handled by ST.

When ST detects a conflict:

ST displays conflict to SC1 and SC4 when within awareness boundaries;
may display conflict and message to SC2.
If SC2 obtains handoffs of both aircraft:
  SC2/ST resolves one/both trajectories;
  SC2 issues clearance(s).
or:
  SC1 and SC4 negotiate a resolution;
  SC1 and/or SC4 issue clearance(s).

(d) "Intersector" scenario.

Figure 6. Concluded.

Intrasector Conflict

If the AT detects a conflict between two aircraft (fig. 6(a)), a cost-effective resolution for one or both trajectories is determined and sent to the ST. If the sector 2 controller (SC2) is configured to be notified of AT advisories, the ST checks the trajectories associated with this resolution against all controller-intent trajectory predictions (including all provisional plans). If the AT resolution is in conflict with any of these trajectories, and SC2 is configured to not allow conflicting AT resolutions, the ST notifies the AT that the advisory cannot be used. If the AT resolution is not in conflict or SC2 is configured to allow conflicting AT solutions to be displayed, the ST displays both ST conflict probe results (if any) and the AT conflict and resolution information to the controller, who then has the option to issue a clearance or reject the advisory. If the ST detects conflicts with the AT resolution, SC2 will have to develop additional clearances through provisional planning to resolve these conflicts. Finally, SC2 notifies the AT of acceptance or rejection through the ST interface. If the advisory is rejected, the AT updates a resolution constraints list and if feasible, AC/AT generates a new resolution for the conflict. If accepted, the advisories are anticipated to reduce overall controller workload by solving conflicts well in advance of potential conflicts while providing cost-effective resolutions based on user preferences.

When the ST detects a conflict within the decision-making time horizon of the controller, it is displayed to SC2. The controller then resolves the conflict using the provisional planning aids provided by the ST. When a satisfactory resolution has been obtained, SC2 issues a clearance to the aircraft. Of course, if one or both of the conflicting aircraft are transitioning, the AT will not have detected the conflict. If both are unconstrained, however, situations may occur where the ST displays a conflict when the AT does not. A possible scenario occurs if the AT resolution advisory has already been rejected or it will not be cost effective until the aircraft is within the controller's decision-making time horizon. If the controller has previously rejected the AT advisory, then the ST resolution is utilized. If an AT resolution is still possible, it is at the discretion of the controller to decide if waiting for a cost-effective AT resolution is appropriate under the current situation. It is expected that a controller would wait for an AT resolution only if traffic conditions were relatively light. Human factors research will be necessary to determine the best display options if both AT and ST resolutions are available.

External Conflict

If both aircraft are unconstrained, en route aircraft (fig. 6(b)), the AT detects a conflict and provides a resolution to the ST, as in the intrasector scenario. If the resolution passes the SC4/ST display-configuration logic (see intrasector scenario case), the conflict information and resolution are displayed to SC4. If both aircraft are within the awareness boundary for SC2 (downstream controller's awareness boundary), the ST displays the conflict to SC2 along with a message that a resolution is pending in sector 4. In this way, SC2 is made aware of upstream decision making that may be of interest; voice communication between the two controllers is not required. SC4 then has the option to either issue a clearance or reject the advisory. As in the previous scenario, the AT is notified of acceptance or rejection of the advisory, and if rejected, the AC/AT may attempt another solution.

If the ST detects a conflict, it displays the conflict information to SC4, even though the conflict occurs outside sector 4. Recall that the conflict is displayed to SC4 even if one or both aircraft are outside SC4's awareness boundary since the upstream controller's awareness boundary is for displaying conflicts with aircraft in sector 2 (conflicts between aircraft owned by the same controller are always detected by the ST, independent of the sector in which the conflict exists). SC4 then uses the provisional planning capability of the ST to resolve the conflict and issue a clearance to the aircraft. The ST also displays the conflict to SC2 if both aircraft are within SC2's awareness boundary (i.e., the downstream controller's awareness boundary). The display of conflict information to the downstream sector allows for SC2 to request an early handoff if desired. If SC2 does not request and obtain handoffs for aircraft A and B, the resolution is performed by SC4 as described.

In general, for conflict resolution involving more than one controller, there is a potential to lower workload through the SC/ST display logic discussed previously. For typical choke-point sectors (such as a low-altitude sector containing a feeder fix), a benefit in providing an upstream controller with an opportunity to resolve the conflict is also possible, thereby redistributing the overall workload. In addition, if an upstream solution is not desired, SC2 has the option to resolve the conflict by requesting early handoffs from SC4. These workload benefits are expected to apply to many traffic situations, so the controllers will have a strong incentive to take full advantage of the integrated tools.

External Intruder Conflict

For the external intruder conflict case (fig. 6(c)), assume that the AT has chosen to modify the trajectory of aircraft A in order to resolve the conflict predicted to occur in sector 2. When the ST receives the conflict resolution packet that contains the advisory for aircraft A, it checks the display logic for SC2. If SC2 is configured to accept AT resolutions, the ST probes for conflicts. Finding none (or if SC2 is accepting AT resolutions with ST conflicts), the ST displays the conflict information and resolution to SC2. If SC4 has also been configured to accept display of AT advisories, the conflict information is displayed with a message that a resolution is pending in sector 2. This message is important to alert SC4 that any clearance issued to aircraft B at this time may cause the AT resolution to be invalidated and that sector 2 should be notified if verbal negotiation is desired. SC4 will also be aware that, if SC2 rejects the advisory, the AT may resolve the conflict by modifying the trajectory for aircraft B. Again, all situational awareness is accomplished without need for voice communication between controllers.

If the conflict has not already been resolved by the AT, the ST detects the conflict and displays the conflict information to SC2 and SC4 after aircraft B crosses the awareness boundary and when the conflict is within the decision-time horizon for each controller. The resolution may be performed by SC2 for aircraft A, by SC4 for aircraft B, or for both aircraft in a negotiated solution. In early implementations, the decision of who will resolve the conflict is made verbally (or procedurally) between the two affected controllers. ST provisional planning aids are expected to be used by the controllers for resolution. Display of conflict information to both controllers may also facilitate an early handoff of aircraft B to SC2 if desired.

Early implementations of the integrated tools may require the AC to perform the role of selecting which aircraft receives the AT advisory. In this example, the AC may know that the traffic situation in sector 2 makes aircraft B more appropriate than aircraft A for receiving a resolution advisory. By placing the integrated tools in operation with functions such as this performed manually, data can be generated that will serve as a basis for a heuristics-based set of aircraft selection criteria, which could later be automated. In addition, the external intruder scenario would benefit greatly from automatic conflict resolution in the ST, which will also be developed for an advanced implementation. ST automatic resolution logic would parallel the logic of the AT; it would remove much of the need for negotiation between controllers for scenarios that require resolutions based upon controller intent.

Intersector Conflict

Again assume that aircraft A is chosen by the AT to resolve the conflict. When the ST receives the AT advisory for aircraft A (fig. 6(d)), it checks the display logic for SC1, and if SC1 is configured to accept, the ST displays the resolution advisory to SC1. If the resolution is acceptable, SC1 then issues the clearance. If SC4 is configured to display AT advisories, the conflict information is displayed with a message that a resolution that involves aircraft B is pending in sector 1. Again, SC4 knows that any clearance issued to aircraft B at this time may invalidate the AT advisory. In addition, SC2 may be informed about the conflict situation by display of the conflict and a message that a resolution involving aircraft A and B is pending in sector 1. SC2 is informed of the conflict if both aircraft are within their respective awareness boundaries, and SC2 has all information needed to know the AT resolution plan. If the AT advisory interferes with SC2 traffic planning, SC2 can ask SC1 to reject the AT advisory and/or negotiate with both controllers for early handoffs.

Assume that the ST detects a conflict between aircraft A and B. SC1 and SC4 have the conflict displayed when both aircraft have crossed the awareness boundaries with respect to sector 2 and are within the controllers' decision-making time horizon. The two controllers then use the ST provisional planning aids and work together to negotiate a solution. SC2 also sees the conflict and aircraft information if SC2's display is configured to show all potential conflicts within sector 2. Again, if SC2 wishes to resolve the conflict, SC2 may ask for early handoffs of both aircraft.

Because the intersector scenario occurs when aircraft in separate sectors have a conflict predicted at a point outside either sector, it is the most complicated situation for sector controller coordination; therefore, it offers the greatest potential for increased efficiency and reduced workload. As in the external intruder scenario, large benefits are expected by using the AT to coordinate conflict resolutions that involve two or more controllers. The manual negotiations currently required for solving multisector conflicts can be reduced significantly, so controllers should have an incentive to use the tool. Early implementation of the integrated tools may require the AC to perform the coordination role for AT advisories. As in the previous scenario, ST automatic conflict resolution (to be implemented in an advanced development) is expected to further reduce the need for verbal controller coordination.

Development Strategy

A phased development approach is proposed that focuses on obtaining benefits as early as possible, validating the concept under real-world conditions, and using operational experience to expand tool capabilities. Table 3 summarizes a three-phase development strategy. Phase 1 concentrates on demonstration of the core capabilities of the individual AT and ST tools and develops the functionality necessary to perform concept validation. Phase 2 provides an initial integrated tools capability, with many of the tool functions performed manually. Both simulation experiments and field testing are an integral part of Phases 1 and 2 development. Phase 3 provides the fully developed integrated system described in this document, including its use as a research platform for advanced concepts. Simulations and field evaluations will be used during this phase to automate many of the manual functions developed in earlier phases. With adequate staffing, the development could be completed in about four years.

Table 3. Development strategy

Phase	Capability	Function
1 Concept feasibility demonstration	AT automatic conflict detection advisories AC manual notification of potential conflicts to area through voice communication SC/ST conflict detection and provisional planning through an auxiliary display	AT Automatic conflict detection Dynamic conflict display ST Auxiliary display Descent advisory aids Manual and limited automatic conflict detection Spacing advisory aids Provisional planning aids
2 Initial operating capability	AT automatic conflict detection advisories AT cost-effective resolution advisories displayed to AC AC/AT provisional planning AT advisories passed to ST (approved by AC) SC/ST automatic conflict detection, provisional planning, and spacing aids display to an auxiliary controller through a fully developed interface	All Phase 1 functions AT Provisional planning aids Cost-effective resolutions ST Mature display interface Full automatic conflict detection
3 Full operating capability	AT conflict detection and resolution advisories AT advisories passed to ST (monitored by AC) SC/ST automatic conflict detection, provisional planning, and spacing aids display at sector via an advanced display interface Fully developed logic for ST probing of AT resolutions and display to sector controller Fully developed logic for AT response to resolution rejection	All Phase 2 functions AT Cost-effective resolutions enhanced to include AC response to AT resolution rejection ST AT resolutions probing logic Display configuration logic Deployable display interface (such as DSR)

Phase 1

In the first phase, the AT and the ST will be developed and evaluated as independent decision support aids. All integration between the AT and the ST is performed manually. A strong emphasis will be placed on development and evaluation of the core capabilities of each tool, and on validation of the fundamental concepts. In addition to laboratory development and evaluation, the tools will undergo operational evaluation in a limited area of en route airspace, involving a few representative sectors (representing both traffic environment extremes) that are chosen based on development and evaluation goals. All display interfaces will be developed only to a level that permits concept evaluation and human-factors-related research.

The AT will provide automated detection of potential conflicts and the probabilities associated with these predictions for en route aircraft in the Center airspace. The dynamic conflict display will be used to provide this information to the AC, who may then notify the appropriate area supervisor of projected areas of high congestion through voice communication. The sector controllers will use the ST to probe for predicted spacing and conflicts between specified aircraft (manual or limited automatic conflict detection), resolve predicted conflicts through provisional planning, and support aircraft in making efficient descents. An advanced radar tracker will be used to make accurate conflict predictions up to 20 minutes in advance.

Research for Phase 1 will concentrate on validating concept feasibility. It will be designed to answer fundamental questions regarding benefits to controllers and users. The research will also focus on defining needed operational procedures (e.g., intersector coordination) and the key elements of a mature display interface through controller evaluations. Some of the concept feasibility issues to be explored are:

- the effectiveness of the dynamic conflict display in assisting the AC in managing the airspace;
- the extent of the assistance the ST provides to the controller in devising and executing traffic plans, especially for managing transitioning aircraft;
- the appropriate sector controller decision-making time horizon for aircraft trajectories with differing traffic management constraints;
- whether the controller considers the benefits received from the ST to outweigh the additional workload required to interface with the tool;
- the expected time horizon for AT cost-effective resolutions based on advanced radar tracker data, and the timeliness of these resolutions in accommodating user preferences and not infringing upon controller intentions;
- the sensitivity of AT cost-effective resolutions to sector controller issuance timing and its effect on resolution effectiveness; and
- the appropriate probability threshold for display of an ST-detected conflict to a controller.

Phase 2

In the second phase, most of the capabilities of the fully developed integrated tools will be achieved by allowing some of the tasks to be performed manually. The AT will provide cost-effective resolutions to the AC, who will then use experience-based judgment to determine whether to accept the solutions or modify them using provisional planning techniques. The AC will then request the AT to send the resolutions to the ST for display to the controller through a fully developed display interface. The controller will provide an input to the ST to notify the AC (through the AT display interface) whether the advisory is accepted or rejected. The ST will provide full automatic conflict detection in addition to the tools provided in Phase 1. Automatic detection should allow the controller to devote more attention to other tasks required in this phase, such as acceptance or rejection of AT advisories. Extensive human factors development is expected during this phase. A limited operational deployment could possibly be achieved after Phase 2; if so, the deployment is expected to be limited to a set of sectors chosen on the basis of benefits and cost.

Phases 1 and 2 will require the use of an auxiliary display and an additional controller to be located at each sector position. To maintain all current radar controller operations, the additional controller will interact with the ST and then will transfer advisory clearances to the radar position (R-side). The display should provide a plan-view graphical interface and a keyboard for input. In addition to the proposed Phase 2 functions, this workstation should have all capabilities currently used to perform sector controller duties, such as accepting handoffs, displaying trend vectors, and providing tools for aiding separation maintenance.

Sector-certified radar controllers will probably be required to interface with the auxiliary display. The handoff position could be responsible for monitoring the additional display for sectors with heavy traffic, and the interphone or flight-data (D-side) position could assume this responsibility for sectors with light traffic. When the ST is fully developed and approved for direct use by both the R- and D-side sector controllers, its functions will be integrated into the sector controller display and the additional controller will no longer be needed.

Research for Phase 2 will include evaluating the utility of AT cost-effective resolutions, evaluating various types of resolutions (e.g., single- or multiaircraft), developing automation algorithms for selecting the best resolution alternative, designing manual switching between AT resolution alternatives, and evaluating appropriate levels of advisories between AC/AT and the sector controller. The mature ST display interface will also be used to identify and resolve any remaining sector controller workload issues. ST filtering of AT conflict resolutions for display to the controller (display configuration logic) will be refined in Phase 2, based on the evaluations and preferences of sector controllers. Some of the development tasks are as follows:

- Develop an automated procedure for selecting an appropriate AT conflict resolution from a set of alternatives, based on awareness of the traffic situation at the sectors involved. For example, selection between two aircraft could be based on the estimated workload (based on factors such as conflict density) of each owning controller.
- Determine appropriate AT followup procedures for rejection of conflict resolutions, based on awareness of the traffic situation at the sectors involved. For example, if a controller rejects an advisory, s(he) may not want AT to attempt another resolution for that aircraft.
- Determine whether duplicating the necessary AC awareness of a sector traffic situation in the AT automation system requires controller (AC and/or SC) inputs that have a negative impact on tool utility.
- Determine, based on controller evaluations, whether the ST display information can be added to radar controller displays, or if it must continue to be displayed separately.
- Determine the effectiveness of an auxiliary display, strip replacement, and/or integrated sector controller display/interface.

Phase 3

The full operating capability of the AT/ST concept will be attained in Phase 3. Development will focus on implementation of functionality for deployment and for a research platform for advanced functionality. After Phase 3, the tools will be available for deployment over the entire Center airspace and in all sectors. An advanced display system (such as the DSR) will be used to display all AT/ST advisories directly to the sector controller. It is expected that most controllers will have incentive to use the tools, although some in light traffic areas may not require them.

In Phase 3, the AT conflict resolution functions should be fully automated, so the AC will no longer be needed to direct the cost-effective conflict resolutions. The AC position will be freed to handle high-level planning tasks in addition to monitoring AT operation. The AC may be able to evaluate Center weather and traffic conditions and make recommendations to users for efficient routing. This scenario may require nonintrusive communication with the aircraft, such as datalink. The communication will also allow the AC to have real-time knowledge of user preferences that can be applied to manage the airspace. Future enhancements may also allow the AC to coordinate user preferences across Center boundaries or to facilitate dynamic resectorization based on actual traffic patterns. The fully operational tool will enable study of these advanced concepts, as well as the evaluation of new airspace management planning tools. Advanced ST research will concentrate on enhancing controller high-level planning under special conditions, such as enabling a transitioning aircraft to meet meter fix crossing restrictions obtained from the CTAS Traffic Management Advisor (TMA) and using datalink to specify user preference or negotiate a trajectory with an airborne FMS. These tasks may require high levels of intersector coordination, so ST automatic conflict resolution will also be studied for deployment in an advanced AT/ST system.

Concluding Remarks

An automated advisory system has been described that achieves many of the benefits of free flight without radically modifying the procedures of ground-based air traffic control. Because it is based on the foundation provided by CTAS, significant operational capability can be achieved in the near future. It also provides a platform for exploring advanced concepts in air traffic management.

The major features of the integrated AT/ST tools are as follows:

- Many of the benefits anticipated for free flight are achieved with only small extensions to current ATC operations and procedures. All current sector controller responsibilities and authority are preserved. All aircraft types can benefit because no new airborne equipment is required.
- The needs of the entire Center airspace are addressed. In en route environments, the integrated tool anticipates and facilitates user preferences, while providing

advisory aids to help the controller solve complex traffic management problems.

- An operational system can be placed in the field quickly, where it can serve as a testbed for new technology. Planned technology exploration includes trajectory negotiation with airborne flight management systems, integration with traffic schedulers such as TMA, and free-flight concepts that transfer responsibility for maintaining separation to the user.
- Sector controllers will have an incentive to use the proposed system because it will improve their capability and reduce their workload. The system is *not* intended to be a replacement for controllers, but an aid to increase productivity.
- The design leads to a logical and systematic evolution. It will be implemented as a series of new functions that will gradually increase system capability. Manual tasks will be automated based on the semi-automatic operation of early deployments, thereby freeing controllers to give attention to more advanced tasks as the design evolves.
- The system is not dependent on planned hardware upgrades, such as DSR, to be successful. It will, however, take advantage of such upgrades.

Although development of this system faces many challenges, no unresolvable implementation issues are anticipated.

References

1. Report of the RTCA Board of Directors' Select Committee on Free Flight. RTCA Inc., Washington D.C., Jan. 1995.
2. Hart, D. C.: Free Flight: An Evolutionary Revolution. Avionics, Apr. 1995, pp. 50–51.
3. Smith, P. J., et al.: Interactions of Airline Operations Control Centers with the Air Traffic Management System. AIAA Paper 96-3854, presented at the Guidance, Navigation, and Control Conference, San Diego, Calif., July 1996.
4. Erzberger, H.; and Nedell, W.: Design of an Automated System for Management of Arrival Traffic. NASA TM-102201, June 1989. Also, Engle, L.: Conflict Detection Tool. Addendum to TM-102201, Oct. 1989.
5. Erzberger, H.: Conflict Probing and Resolution Algorithms. Presented to FAA/AUA-500 management, NASA Ames Research Center, May 2, 1996.
6. Green, S.; and Vivona, R.: Field Evaluation of Descent Advisor Trajectory Prediction Accuracy. AIAA Paper 96-3764, presented at the Guidance, Navigation, and Control Conference, San Diego, Calif., July 1996.
7. Green, S.; den Braven, W.; and Williams, D.: Development and Evaluation of a Profile Negotiation Process for Integrating Aircraft and Air Traffic Control Automation. NASA TM-4360, Apr. 1993.
8. Benjamin, S. G.; Brundage, K. J.; and Morone, L. L.: The Rapid Update Cycle. Part I: Analysis Model Description. Technical Procedures Bulletin No. 416, NOAA/NWS, 1994. [National Weather Service, Office of Meteorology, 1325 East-West Highway, Silver Spring, MD 20910. Also available on the World Wide Web at http://www.fsl.noaa.gov/frd-bin/tpbruc.cgi.]
9. Slattery, R.; and Green, S. M.: Conflict Free Trajectory Planning for Air Traffic Control Automation. NASA TM-108790, Jan. 1994.
10. Interface Requirements Specification for the Sensor Data Acquisition and Processing System (SDAPS). Contract No. DCA100-94-D-0015, prepared for NASA Ames Research Center by BDM Federal, Inc., Boulder, CO 80301, Mar. 1996.

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13. ABSTRACT *(Maximum 200 words)*

The Federal Aviation Administration is trying to make its air traffic management system more responsive to the needs of the aviation community by exploring the concept of "free flight" for aircraft flying under instrument flight rules. A logical first step toward free flight could be made without significantly altering current air traffic control (ATC) procedures or requiring new airborne equipment by designing a ground-based system to be highly responsive to "user preference" in en route airspace while providing for an orderly transition to the terminal area. To facilitate user preference in all en route environments, a system based on an extension of the Center/TRACON Automation System (CTAS) is proposed in this document. The new system would consist of two integrated components. An airspace tool (AT) focuses on unconstrained en route aircraft (e.g., not transitioning to the terminal airspace), taking advantage of the relatively unconstrained nature of their flights and using long-range trajectory prediction to provide cost-effective conflict resolution advisories to sector controllers. A sector tool (ST) generates efficient advisories for all aircraft, with a focus on supporting controllers in analyzing and resolving complex, highly constrained traffic situations. When combined, the integrated AT/ST system supports user preference in any air route traffic control center sector. The system should also be useful in evaluating advanced free-flight concepts by serving as a test bed for future research. This document provides an overview of the design concept, explains its anticipated benefits, and recommends a development strategy that leads to a deployable system.

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